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ON THE ROLE OF THE TURBULENT MIXING IN THE FORMATION OF THE GROUND-LEVEL OZONE CONCENTRATION IN THE KOLA PENINSULA

V.I. Demin (*Polar Geophysical Institute, Russia*)
A. Yu. Karpechko, E. Kyre (*Finnish Meteorological Institute, Sodankyla, Finland*)

Abstract. Maximum in the monthly ozone concentrations on the ground which is reached in the surface layer because of turbulent mixing are calculated from the climatic values of the maximum altitude of the mixed layer above the town of Apatity and the data of the ozone sounding station Sodankyla, Finland. In the Kola Peninsula, the maximum monthly ozone concentrations on the ground do not exceed those at the upper boundary of the mixed layer. This is an evidence of ground ozone field formation by the turbulent mechanism (the supply of ozone to the surface layer occurs by the eddy transfer from the upper boundary layer which is more enriched with ozone).

Introduction

According to the common view, the ozone sources in the surface layer are turbulent diffusion from the upper troposphere layers and photochemical generation in the surface layer. However, the synchronous measurements of ground ozone concentration at several points of the Kola Peninsula with the different level of anthropogenic pollution have not shown any signatures of photochemical generation in the surface layer. The maximum ozone concentrations in the centre of Apatity town, in the suburbs and in the countryside (Lovozero) are nearly the same (± 2 ppb) in summer period [1, 2]. This suggests that for the conditions of the Kola Peninsula the basic (and most likely the only one) mechanism of ozone supplying into the surface layer is the turbulent exchange.

It is known that the ozone concentration nearly always grows with height from the ground to the upper border of the boundary layer, reaching the values of 50-60 ppb, known from the vertical ozone sounding [1]. A schematic vertical profile of ozone mixing ratio in the troposphere is shown in Figure 1.

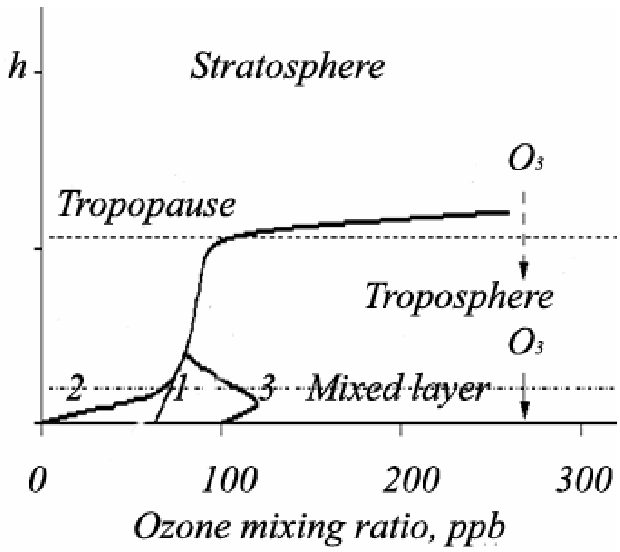

Figure 1. Schematic vertical profile of ozone mixing ratio in the troposphere

An intensive turbulent mixing causes smoothing of the vertical ozone profile within the mixed layer, so that the maximum ground-level ozone concentration is close to that at its upper boundary (profile 1 in Figure 1). In the daytime, such mixing is caused by the thermal turbulence resulting from statically unstable stratification of the atmosphere. For the case of stable stratification (at night or in winter) this is due to the dynamic turbulence caused by some peculiarities in the vertical wind structure.

Profile 2 in Figure 1 refers to the reduced turbulent exchange (for example, at night). We will imply the photochemical generation if the surface ozone concentrations are greater than those at the upper boundary of the mixed layer (profile 3 in Figure 1).

It is evident that the maximum ozone concentrations in the surface layer, related solely to the turbulent mixing, should not exceed those at the upper boundary of the mixed layer. Then we can estimate the turbulent exchange contribution to the formation of the ground-level ozone field, provided the data on the altitude of the mixed layer and ozone vertical distribution are available.

Data and Methodology

The maximum altitude of the mixed layer has been determined from the dynamical model of the boundary layer [2, 3] on the assumption that the maximum altitude of the mixed layer and of the boundary layer is nearly the same (the corresponding correlation coefficient is 0.95).

Because of the short period of ozone measurements in the town of Apatity, we replaced the ozone concentration in Apatity averaged over many years for that observed in Lovozero, since, according to synchronous monitoring, the monthly averages of these quantities differ not more than by 2 ppb.

The nearest ozone sounding station (Sodankyla, Finland) is 300 km to the south-west from Apatity. We also note that the basic features of daily and annual cycle in the ground-level ozone concentration in the north of Finland (Oulanka) and in the Kola Peninsula are very similar.

In this case, the monthly average ozone concentrations at the upper boundary of the mixed layer are considered to be equal to those in Sodankyla.

Results and discussion

The calculated average ozone concentrations at the upper boundary of the mixed layer and maximum average ground-level ozone concentrations in Lovozero are shown in Fig. 2.

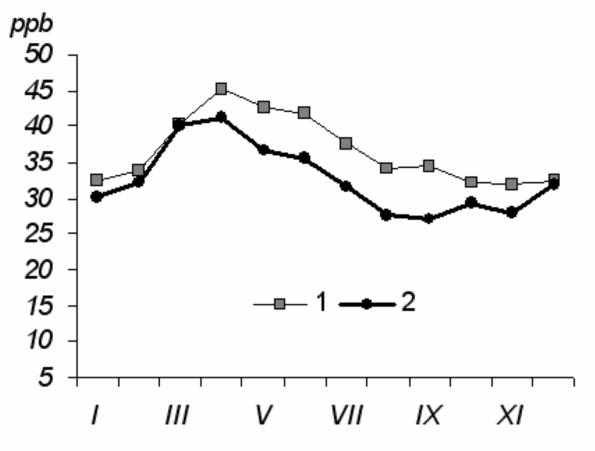

Figure 2. The average ozone concentrations at the upper boundary of the mixed layer (1) and average maximum ground-level ozone concentrations in Lovozero (2).

As we can see, the maximum monthly ground-level ozone concentrations in the Kola Peninsula do not exceed the average ozone concentrations at the upper boundary of the mixed layer. This is an evidence of ground-level ozone field formation by the turbulent mechanism (a supply of ozone into the surface layer is by the eddy transport from the upper parts of the boundary layer, which is more enriched with ozone).

The discrepancy between the calculated and measured values is the smallest for the cold half-year (October through March), and the greatest for summer. This is due to the fact that in winter period, the rate of ozone destruction above the snow cover is small and the vertical ozone profile in the surface layer is smoother, while in summer there is a significant ozone destruction on the underlying surface.

The analysis of diurnal ozone variations in Lovozero and on the mount Lovchorr of the Khibiny mountain range (1089 m) located 50 km from Lovozero evidences the correctness of the above estimations. In May, when the average maximum altitude of the mixed layer does not exceed 750 m, the maximum ground-level ozone concentrations differ much from the ozone concentrations on the top of the mount Lovchorr. In July, when mixed layer maximum altitude (1050 m) becomes comparable with the altitude of the mount Lovchorr, the maximum ground-level ozone concentration in Lovozero approaches in the afternoon that on the top of mount Lovchorr.

It should be noted that the diurnal variation in the ground-level ozone concentration in various seasons in the Kola Peninsula is in accordance with the common view on the diurnal variation of the dynamic processes in the surface layer and boundary layer.

In summer, the basic contribution to the turbulent mixing is due to the convection processes, which are determined by the temperature of the ground. This is the diurnal variation, resulting from the diurnal changes in the input of radiation energy. Thus we obtain the daily variation of ground-level ozone, and a correlation between the ground-level ozone concentration and air temperature (0.47). The coefficient of the correlation between the concentration of ozone and wind velocity is low (0.28) in the afternoon, however, it reaches 0.47 at night, when the thermal stratification is stable and the role of dynamic turbulence is much greater.

During the winter period, in the conditions of weak luminosity or polar night, the net radiation of the underlying surface is negative all the time, so that there is no energy for the regular daily reorganization of the dynamical processes in the boundary layer. For the conditions of a persisting synoptic situation, there is no diurnal variation in the ground-level ozone concentration, not considering the moments of wind velocity strengthening (or vertical wind shear), when an intensive turbulent mixing involves a thicker layer of the atmosphere. It accounts for an increase in the seasonal correlation between the ground-level ozone concentration and wind velocity (r=0.48).

As there is no difference, which instability (dynamic or thermal) leads to the ozone supply to the surface layer from the upper atmosphere layers, there are no essential distinctions between the average maximum ground-level ozone concentrations in the Kola Peninsula in the periods of the polar day and polar night (30 ppb in July and 29 ppb in December).

Conclusions

1. The monthly average maximum altitudes of the mixed layer for the central area of the Kola Peninsula and the monthly average ozone concentrations at its upper boundary are calculated.

2. It is shown that monthly average maximum ground-level ozone concentrations in the Kola Peninsula do not exceed the average ozone concentrations at the upper boundary of the mixed layer which evidences the turbulent mechanism of ground-level ozone field formation in Arctic.

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References

1. Ozone Data for the World // Canad. Environ.service/ WMO: Downsview-Ontario. 1974—2001
2. Берлянд М.Е. Прогноз и регулирование загрязнения атмосферы. Л., Гидрометеоиздат. 1985.272 с.
3. Климатические условия распространения примесей в атмосфере. Справочное пособие. Л., Гидрометеоиздат, 1983. 328 с.